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Response Surface Mapping Technique Aids Warfighters

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14. ABSTRACT

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Response Surface Mapping Technique Aids Warfighters

Scientists apply innovative data mining and visualization techniques to real-world weapon penetration mechanics problems.

When weaponeering a target, military planners pinpoint a detonation location that will result in the desired damage to the entire target, or even a particular area within the target. The warfighter then selects the most suitable delivery platform—aircraft, weapon, guidance package, release altitude, and speed—for inflicting the appropriate damage to the target. Determining the proper combination of variables capable of producing the desired effect on a hardened target requires the warfighter to understand the penetration dynamics of the weapon; it also relies on the individual's ability to adjust the variables within his or her control, as necessary. For a scenario in which the destruction of a specific target is often coupled with the mitigation of collateral damage, it is imperative that the warfighter make proper decisions regarding weapons selections. AFRL scientists, collaborating with other Department of Defense agencies, applied innovative data mining and visualization methods to aid warfighter efficiency and effectiveness in making these choices.

AFRL, the Defense Threat Reduction Agency (DTRA), and the US Army Engineer Research and Development Center (ERDC) regularly conduct research to explore the effects of weapons penetration on hardened and structural targets. One result of this research has been the development of numerical models and algorithms both for predicting projectile penetration into geologic and structural targets and for estimating the cratering and other damage from subsequent weapons detonations. These models and algorithms are incorporated in a unique suite of software tools known as PENCURV+. PENCURV+ includes a weapons penetration model (PENCRV3D) that calculates three-dimensional trajectories of rigid, axisymmetric projectiles impacting complex geologic/structural targets composed of curvilinear material layers.[1] Prior to the development of PENCRV3D, the simulation of hard-target munitions penetration performance was limited to fairly benign weapon/target conditions. Furthermore, the penetration codes used in these early simulations employed oversimplified empirical models to calculate penetration dynamics. During the 1990s, joint AFRL, DTRA, and ERDC testing and development efforts improved and validated the algorithms and models and thus enabled researchers to generate more accurate weapons penetration solutions.

In early 2000, Mr. Bruce Brown (Northrop Grumman), a former F-117 pilot supporting DTRA's Hard-Target Defeat initiative, began applying advanced design theory to the challenge of hard-target weaponeering. The design theory he used is based on a two-part visualization approach: (1) visualize the place you want to be (aspiration space), and (2) visualize where you can be (design space) in terms of key system variables.[2] In this context, "aspiration space" represents the penetration depth, "design space" encompasses the guidance kit impact performance, and "key system parameters" refer to impact angle and velocity.

Mr. Brown's application of this design theory led to the response surface map (RSM), a graphical representation of the variables. To create an RSM, he first plotted lines of constant depth (acquired from multiple PENCRV3D runs) to show how penetration depth changed as impact angle and velocity changed. He then used the same chart to plot guidance kit performance envelopes using results predicted for a variety of weapons release conditions. An advantage of this approach was that all weapons using the same bomb body could be plotted on the same chart, providing nearly all of the information an analyst would need to solve a particular penetration problem.

Prior to implementation of the RSM, mission planners made an initial assumption of release conditions(e.g., 20,000 ft altitude and 500 kts airspeed), ran the PENCRV3D program, and evaluated the results. If the weapon failed to achieve the desired penetration depth, the planner selected either a new set of release conditions or a different weapon and then ran the analysis again. The advent of the RSM technique enabled mission planners to run a single analysis to determine the penetration outcome for multiple guidance kits and release conditions.

The development of the RSM method for penetration performance analysis occurred parallel to an effort by Major Craig Baker, of the US Air Force Weapons School (USAFWS), to rewrite the hard-target weapons selection procedures as taught by the school's F-16 division. Maj Baker solicited the help of Mr. Brown and Mr. Joseph Renick (also of Northrop Grumman), and their subsequent collaboration sought to blend the weaponeering resources already in place: RSM, which brought innovation to information presentation; PENCRV3D, which addressed the science and engineering of hard-target projectile penetration; and USAFWS, which tackled the requirement to provide practical guidance for the warfighter. The RSM was at the core of this convergence, and the USAFWS redesigned its hard-target (tunnel and bunker target) defeat strategy to exploit its use. To promote this new approach, DTRA and the USAFWS created a "roadshow" to train mission planners in the field and the joint AFRL/DTRA/ERDC team published several articles in *Weapons Review,* a USAFWS publication.

Although the approach to hard-target defeat planning was changing, the process of creating the initial RSMs remained a tedious work effort that required hours to complete. Analysts eventually adopted a spreadsheet method to generate solutions faster, but producing an RSM remained a lengthy process known to only a few people. Despite the effort involved, USAFWS analysts continued to generate manual solutions to support Operation SOUTHERN WATCH.

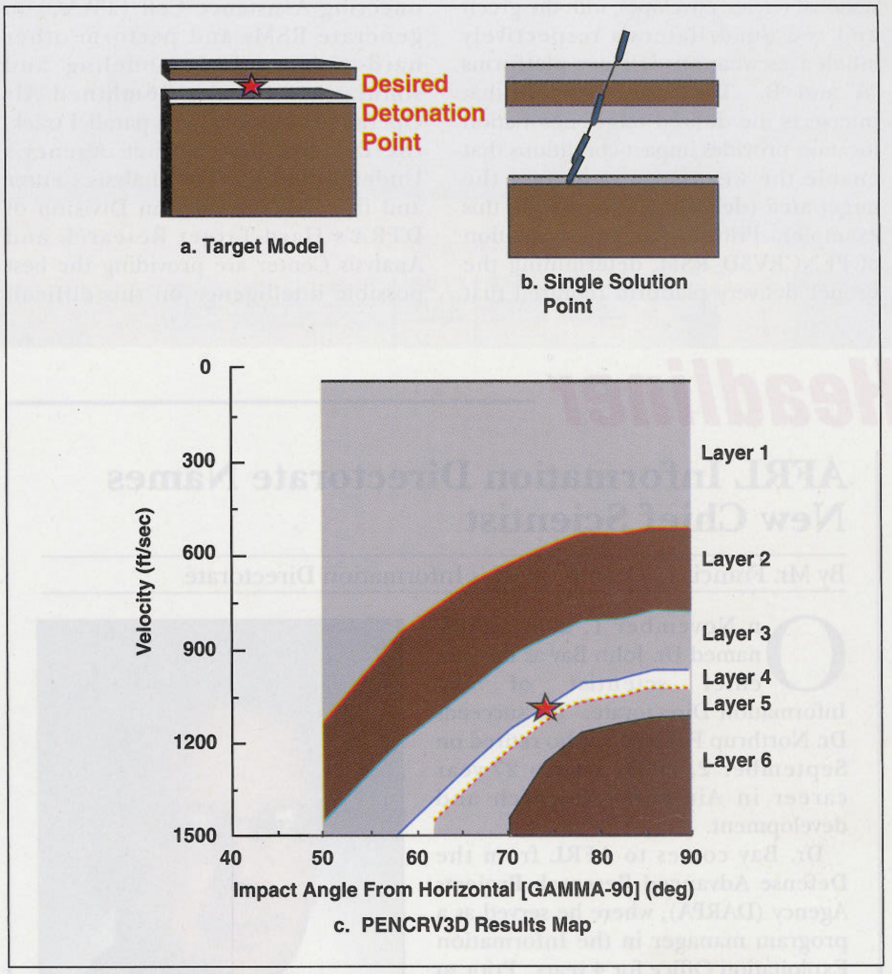
In 2002, a DTRA-funded team of AFRL and ERDC engineers began developing the algorithms that would

eventually create RSM charts automatically. The team's technical objective was to automatically generate, organize, and present relevant information acquired from a large number of penetration mechanics simulations in a single display that would enable analysts to quickly recognize and interpret trends in the results. To meet this objective, the team incorporated RSM techniques for mapping penetration simulation results from Cartesian space into an alternate vector space (impact angle and velocity), thus allowing the analyst to view large amounts of data in one chart. To accomplish this data transformation, the algorithm first "discretizes" the alternate vector space into a grid. It then generates penetration results for the points defining that grid. The algorithm uses nonlinear interpolation techniques both to create the RSM charts and to determine how the penetration results vary with the parameters defining the vector space. For instance, the algorithm can compute contours of constant penetration depth to determine which combinations of input parameters provide a given penetration depth.

In early 2003, the AFRL/ERDC team integrated the algorithms into PENCURV+, creating the PENCRV3D_RSM code. The PENCRV3D_RSM software automatically performs hundreds of weapons penetration trajectory simulations before integrating the results into a single RSM chart so that planners can visualize the comprehensive data. An invaluable tool for analysis activities requiring the execution of numerous parametric simulations, PENCRV3D_RSM augments efforts such as mission planning, weapons development, and unexploded ordnance work. The team completed the software product about a month prior to the start of Operation IRAQI FREEDOM. Analysts were therefore able to use it immediately to plan missions against hard targets.

Figures 1a,1b, and 1c illustrate the use of PENCRV3D_RSM for a mission planning application. As noted previously, target weaponeering involves an analyst's selection of a detonation location that will result in the desired damage to the target, and in many cases, this means the analyst must plan the detonation for a particular chamber or area within the target (see Figure 1a). After making the appropriate selections, the analyst runs PENCRV3D to simulate the given weapon's trajectory into the target based on the predetermined set of impact conditions (see Figure 1b). For a given weapon and target, the PENCRV3D_RSM program will automatically execute PENCRV3D for many sets of impact conditions and map the results into an impact angle/velocity space (see Figure 1c). As Figure 1c illustrates, each point within the plot represents a PENCRV3D penetration simulation. At this point, the analyst can click on any chart location to display the corresponding trajectory.

The Figure 2 depiction of overlaid platform performance data illustrates how RSM can aid the warfighter's



Figures 1a,1b,1c. RSM charts for a complex, layered target

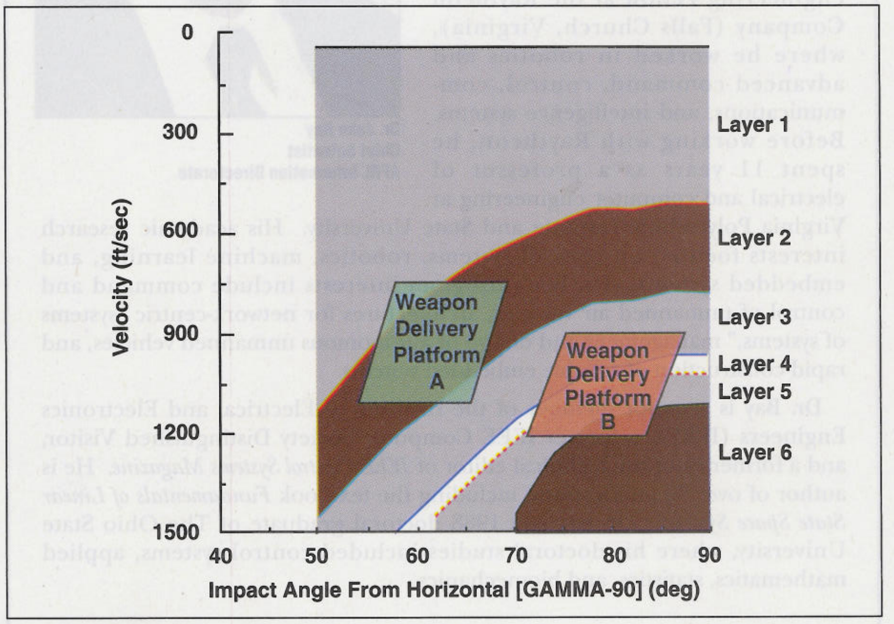


Figure 2. Notional release envelopes overlaid on an RSM chart

selection of the delivery platform for reaching the desired detonation location. Once the warfighter selects the platform (aircraft and guidance package), he or she can overlay a release envelope onto the RSM chart. Figure 2 (on previous page) shows two notional release envelopes, with the green and red quadrilaterals respectively labeled as weapon delivery platforms "A" and "B." The release envelope that intersects the desired target detonation location provides impact conditions that enable the weapon to penetrate the target area (delivery platform B, in this example). Prior to the implementation of PENCRV3D_RSM, determining the proper delivery platform required that an analyst run multiple PENCRV3D simulations. The PENCRV3D_RSM mission planning tool enables the creation of an RSM chart in seconds, allowing the warfighter to quickly select the appropriate delivery platform.

DTRA formed the Targeting Weaponeering Assistance Cell (TWAC) to generate RSMs and perform other hard-target defeat modeling and simulations for the Combined Air Operations Center. On a parallel track, the Defense Intelligence Agency's Underground Facility Analysis Center and the Characterization Division of DTRA's Hard-Target Research and Analysis Center are providing the best possible intelligence on this difficult target set. The combination of target intelligence and hard-target expertise has enabled TWAC planners to conduct more than 150,000 PENCRV3D-based simulations on the most hardened targets in Iraq. The Master Air Attack Planning Cell has used the RSM packages to allocate weapons and platforms for strikes in Baghdad and throughout Iraq. This enhanced mission planning capability, combined with the availability of new weapons, has enabled warfighters to defeat hard targets more efficiently than during the first Gulf War. As Mr. Renick, a member of the TWAC, asserts, "Without the special PENCRV3D_RSM code, it would have been impossible for the TWAC to process the assigned target list before initiation of the air campaign."

Based on the proven success of the RSM technique, researchers are integrating PENCRV3D_RSM into numerous hard-target analysis programs. Likewise, DTRA is funding the development of additional RSM-based mission planning tools. Mr. Brown is currently working with Ms. Dorothy Boswell, of Applied Research Associates, and Dr. Mark Adley, from ERDC, to automate the creation of RSM mission planning charts in the next generation of the PENCRV3D_RSM code. In a related effort, scientists from the Weapon System Evaluation Program and several Air Force units are using the current version of the code to evaluate the results of various hard-target missions.

Ultimately, the RSM story is about teamwork across government agencies, solid science and engineering practices, and direct interaction with the warfighter. The author wishes to specifically thank Mr. Brown and Mr. Renick, Maj Baker, Dr. Adley, and Mr. Michael Giltrud and Dr. Robert Hastie, of DTRA, for their outstanding contributions to the work described in this article.

Mr. Bruce C. Patterson, of the Air Force Research Laboratory's **Munitions Directorate**, *wrote this article. For more information, contact TECH CONNECT at (800) 203-6451 or place a request at* ***http://www.afrl.af.mil/techconn/index.htm****. Reference document MN-H-05-15.*

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